Spawning Activity and Migratory Characteristics of American Shad and Striped Bass in the Cape Fear River, NC

2007 Annual Report

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Introduction

The Cape Fear River travels south/southeast, approximately 320 km from the confluence of the Deep and Haw rivers in Chatham County North Carolina, to the Atlantic Ocean, 40 km below Wilmington, North Carolina (Walburg and Nichols 1967). Anadromous fish species (those that live in saltwater and migrate into freshwater to spawn) have long been an important resource within the Cape Fear River basin. In the 1800s, McDonald (1887) reported that sturgeon (*Acipenser spp*.) dominated the river's fishery. Also during this same period, American shad (*Alosa sapidissima*) landings approached 200,000 pounds with incidental catches of striped bass (*Morone saxatilis*) totaling 1200 pounds (McDonald 1887). Unfortunately, populations of these species within the Cape Fear have experienced significant declines since that time.

Studies in the early 1900s led to a recommendation that management restrictions be placed on the American shad fishery in the Cape Fear River to help restore depleted stocks (Cobb 1906). Currently, the Cape Fear striped bass population remains among the lowest of North Carolina's coastal rivers (Patrick and Moser 2001; Ashley and Rachels 2006). And as for the once common sturgeon, only a small population of Atlantic sturgeon (*A. oxyrinchus*) and very small number of shortnose sturgeon (*A. brevirostrum*) are present in the system today (Winslow et al. 1983; Moser and Ross 1995).

Declines in anadromous species in the Cape Fear have been attributed to the same variety of anthropogenic effects (overfishing, pollution, development, dam construction) that have impacted many other Atlantic coastal rivers (Winslow et al. 1983; Winslow 1994). One of the most conspicuous of these effects is dam construction, which has been shown to alter habitat, block the migration of anadromous fishes to upstream spawning areas, and subsequently limit the availability of nursery habitat for progeny (Beasley and Hightower 2000; Burdick and Hightower 2006). In the Cape Fear River, three low-head lock and dam structures were constructed between

1913 and 1934 by the United States Army Corp of Engineers (USACOE) for the purpose of commercial navigation (Moser et. al. 2000). Fish ladders were constructed at each of the three lock and dam structures, but anadromous fish were unsuccessful at utilizing them (Davis and Cheek 1967). Subsequently, in 1962, a program was implemented through an agreement among the North Carolina Wildlife Resources Commission (NCWRC), USACOE, and United States Fish and Wildlife Service (USFWS) to use the lock at each dam to move fish upstream to continue their spawning run (Fischer 1983; Moser et. al. 2000). Moser et. al. (2000) estimated that passage efficiency rates for American shad at lock and dam #1 (LD-1) were 18-61% over a three-year period, with higher rates resulting from changes in lockage frequency, extended late-season operation, gate arrangement and increased attractant flow. Additional telemetry studies from 2003 to 2004 (when 10 or more individuals with transmitters reached LD-1) found passage rates were 26-33% for American shad and 23-61% for striped bass (CZR 2004). Currently, the USACOE conducts fish lockages at each dam three times a day, from March – June and once each day throughout the remainder of the year, given normal flow conditions (R. Hall, USACOE, personal communication, 10/30/07). The procedure entails opening one side of the lower gate of the lock for an extended period of time while valves within the upstream gate are opened to create an attractant flow. The lower gate is then closed and the water level inside the chamber is raised to that of the upstream pool. The upper gate is then opened to allow fish to move upstream (R. Hall, USACOE, personal communication, 4/4/07).

Despite the success of these efforts there still remains a large proportion of fish that are denied access to upstream spawning areas. That problem has prompted new discussion about ways to further improve anadromous fish passage on the Cape Fear River. The goal of this project is to characterize the current patterns of migration and spawning activity for American

shad and striped bass within the Cape Fear River. Tracking the movements of these fish, along with conducting egg and larval fish surveys, will help to identify areas of concentrated spawning activity, uncover patterns and preferences in habitat characteristics, and further assess the impact of the three dams on their distribution. Ultimately, the new data provided by this study will serve as a useful tool to aid in management decisions regarding the recovery of this extremely important resource.

Methods

Field research for this study consisted of two major components: egg and larval sampling and tracking movements of sonic-tagged fish. Egg and larval surveys were done twice a week from March 9 through May 31, 2007 at five locations (Figure 1). One sampling location was established below each lock and dam (rkm 97, 149, and 186), typically in high flow areas within ½ km of the dam. All lock and dam sites were sampled during evening hours and most often just before or after sunset. A fourth site was established near the city of Fayetteville, approximately 3 km above the NC 24 Bridge (rkm 226). The final sampling location was located just east of the city of Lillington, below a shoal at the NCWRC Wildlife Road access area (rkm 273). Latitude and longitude for each site was determined using a Garmin Etrex Vista handheld GPS unit (Table 1) and surrounding physical landmarks were noted for reference.

Depth at each site was measured using an Eagle Cuda fishfinder. Temperature and dissolved oxygen readings were taken using a Yellow-Springs Instrument handheld multi-parameter water quality unit (YSI 85). Plankton samples were taken using a bongo style net consisting of two 0.3-m hoops with 500-µm mesh, 5/1 tail-to-mouth ratio nets, and solid cup cod ends. A 6.8-kg torpedo weight was attached to the crossbar of the frame in order to reach bottom. A General Oceanics Model 2030R standard flowmeter was used to calculate the volume of water

sampled during each collection effort. A 2.27-kg weight was attached to the lower line of this unit in order to reach bottom. Once in position, both rigs were slowly lowered off the stern of the vessel until the weights made contact with the bottom. This would begin the 15-minute oblique tow, in which the instruments were raised at consistent intervals in order to sample the entire water column evenly. The rope attached to each instrument was marked in 0.3 m increments to ensure consistency between retrievals. After 15 minutes, the net and the flowmeter were removed from the water. The walls of the net were washed down into the solid cup ends and the contents of the cup were then fixed with a 5-10% solution of formalin and labeled for processing. Processed American shad eggs were categorized by developmental stage using criteria provided by Jones et. al. (1978). Stages were as follows: (1) first two hours of development ; (2) 4 to 6 hours ; (3) around 20 hours ; (4) around 38 hours ; (5) 42 hours and beyond. An exponential curve was fitted using least-squares to the number of stage-1 American shad eggs collected at the four lowermost sites.

The tracking portion of this project consisted of several phases, one of which was to determine how American shad would react to the proposed tagging procedure. The tag retention study was conducted at the NCWRC's Watha Hatchery in Pender County. NCWRC biologists collected 25 American shad on April 2, 2007 by boat electrofishing below LD1. The fish were transported to the facility in a 378 liter, round live-well and placed into a large round indoor hatchery tank for recovery. On April 4, 2007 we implanted VEMCO V9-1L-R04K coded transmitters in ten of the fish, with the remaining fish serving as controls. Tagged fish were netted from the tank, quickly measured, assigned gender if possible, implanted with a transmitter, and returned to the tank. Transmitters were 24 mm long, weighed 2.2 g in water, and were inserted into the gut through the esophagus using a small length of clear tubing with

glycerin lubricant. The fish were held for a five-day observational period over which mortality was recorded.

The next phase of the telemetry work involved collection of American shad and striped bass from below the locks & dams to transport upstream for tagging and release. Fish were again collected by NCWRC biologists by elctrofishing and were held in a round 378 liter onboard livewell, which included a circulating system, and an airstone that was fed directly from a tank of 100% oxygen. The first six striped bass collected were taken directly to the Pechmann Fishing Eduction Center in Fayetteville to be held until they could be processed. All other fish were transported directly from the collection location to the release point, just downstream of the NC 24 Bridge (rkm 219). On several occasions, fish were moved from the NCWRC livewell into a 378 liter plastic oval tank onboard our Boston Whaler. This tank was equipped with a circulation system, sprayer hose, and oxygen-fed airstone, and held the fish during transport to the release site.

At the release site, live fish were measured (total length, TL, in mm), sexed if possible, tagged, and placed into an instream holding pen. The American shad were implanted with the same type of VEMCO transmitter as discussed in the tag retention section. Striped bass received a similar but larger (36 mm, 6 g in water) V13-1L-R64k coded transmitter. All transmitters emitted a unique sequence at random time intervals that allowed for individual identification. Time intervals were set at once every 30-60 seconds for American shad and 60-90 seconds for striped bass.

The holding pen was a 1.5 m wide x 3.4 m long x 1.3 m deep floating oval frame made of polyvinyl chloride (PVC) pipe, with custom 0.63-cm ace knotless netting from the Midlakes Corp. in Knoxville, TN. The number of fish tagged on each occasion varied depending on the

number captured, so different combinations of tagged and untagged fish were held in the pen to see if it affected the response of the tagged fish upon release. Also, some fish were held in the pen for 24 hours prior to release while some were released directly into the river. Holding times, pen arrangements (door open vs. door closed), number of fish in the pen, and release (immediate vs. delayed) was purposely varied among release events in order to see how these different approaches affected tagged fish behavior after release.

Monitoring fish movement after release was the final phase of the telemetry work. We incorporated two different methods of transmitter detection. One method included an array of six stationary VEMCO VR2W receivers (Figure 2). One receiver was deployed at I-295 bridge (rkm 231), NC 301 bridge (rkm 220), I-95 bridge (rkm 212), and LD3 (rkm 186) on April 12, 2007, and at LD2 (rkm 149) and LD1 (rkm 97) on April 19, 2007. All receivers, except the one at the 301 bridge which was missing, were removed from the river on June 12, 2007. Each stationary receiver was attached to a length of braided nylon rope with an 11.34-kg plate weight attached to the bottom and a large foam float tied to the top. This arrangement allowed the receiver to be suspended in the water column in order to maximize reception capability. A second length of rope was tied to a permanently fixed object in the river and then attached to the weight to prevent the receiver from being swept downstream during high flow events. These receivers operated continuously and automatically logged any detection event. The unique tag identification number, date, and time were recorded for each signal detected by the receiver.

The other method was manual tracking by boat, using a portable VEMCO VR100 receiver equipped with either a VH165 omni-directional or VH110 directional hydrophone. The hydrophone was mounted onto a length of PVC and attached to a bracket that was clamped to the bow of the boat. A removable clip was used with the bracket in order to raise and lower the

hydrophone as needed. Searches were conducted by motoring downstream at a slow to moderate speed or by drifting freely during periods of high flow. If a signal was detected, the boat was held in position so that a more precise location of the fish could be obtained. This was achieved by manually turning the hydrophone until a direction of strongest signal strength was established. The boat would then be moved in that direction until the signal strength was close to 100%. Coordinates for this location would be logged using the receiver's internal GPS unit. Date, time, depth, temperature, dissolved oxygen, and flow rate measurements were also taken, along with a Ponar Grab sample to determine substrate. Streamflow and precipitation data were obtained from the USGS at http://waterdata.usgs.gov/nwis/sw for USGS site number 02105769 at LD1 on the Cape Fear River.

Results

Average water temperature, dissolved oxygen level, and sample volume were fairly similar among plankton sampling sites (Table 1). Average depth ranged from 1.7 m at the uppermost site to 7.0 m at the lowest site (Table 1). Streamflow at LD-1 ranged from 248 m^3/s to 5486 m^3/s, with an average of 1752 m^3/s for the study period (Figure 3). Eighteen rainfall events, totaling 23.42 cm, occurred from March 1 to June 1, 2007, with five events resulting in accumulation greater than 1.27 cm. The average daily precipitation for the period was 0.25 cm, with a maximum event of 9.70 cm on April 15, 2007. Water temperatures during the study period were 10.2°C – 28.0 °C, with American shad eggs collected at 14.8 °C – 25.5 °C (Figure 4).

A total of 588 American shad eggs were collected from the five sampling locations (Table 2). The first American shad egg collected during the study was from below lock and dam #2 (LD-2) on March 26, 2007. This collection came one week after the USACOE began their

multiple daily locking procedures at each lock and dam. The first date of collection at LD-1 was March 28, compared to April 12 for LD-3 and April 26 for Fayetteville. The last date of collection at any site was May 30, which was one day prior to the last day for plankton sampling in 2007. Site LD-1 yielded 475 eggs or 81% of the total number collected, compared to 82 eggs (14%) at LD-2, 29 (5%) from below lock and dam 3 (LD-3), and 2 (0.003%) from the site near Fayetteville. No eggs were collected from the Lillington site. Water levels at this location greatly decreased over the course of the study period and therefore the sampling location was moved to an area of concentrated flow, just below the shoal upstream of the boat ramp. However, this location was relatively close to the shore and may have been somewhat marginalized.

Stage 1 eggs (age 0-2 hrs) made up 95% of the total, with 4% found to be in stage 2. The numbers of stage-1 eggs collected below the three locks and dams and the lowest site above LD-3 declined at an exponential rate (Figure 5). The fitted curve indicated that egg density decreased by about 80% with each additional lock and dam. Egg densities (number per 1000 m^3) ranged 0-3080 eggs/1000m^3, with the highest rates occurring below LD-1 (Figures 6-9). Spawning activity tended to be highest just after a decrease in streamflow, particularly the decrease occurring in late April.

Sixteen American shad larvae were collected (Table 2). Ten of the larvae were collected below LD-2 between May 15 and May 30, 2007 and 6 were collected below LD-1 between May 22 and May 28, 2007. No striped bass eggs or larvae were collected but many other non-anadromous larvae were collected and are awaiting identification confirmation.

The tag retention experiment resulted in an 80% post-tagging survival rate for tagged fish (Table 3). Three of the original 25 fish died in transit before the tagging procedure and 1 fish died due to improper tag insertion (ruptured viscera), leaving 21 fish for the experiment. Only 2

of the 10 tagged fish died (one within 12 hours of tag insertion and the other three days after tag insertion) and none of the 11 untagged fish died.

Twenty American shad and 20 striped bass were tagged and tracked during the study. The group of American shad consisted of eight males averaging 440 mm TL and 12 females averaging 503 mm TL (Table 4). The striped bass group included 16 males averaging 626 mm TL and 4 females averaging 749 mm TL (Table 5).

Eighteen American shad were relocated at some point in the study, based on combined data from manual tracking and stationary receivers (Figures 10-13). Twelve American shad moved upstream of the release site (rkm 219) and 6 moved downstream. Three of the six fish moving downstream went below LD-3, and none of those made secondary upstream movements. American shad 2428 was detected at LD3 and made a secondary upstream movement, but it is unclear as to whether or not the fish passed over the dam and then back upstream. Three American shad moved upstream of the uppermost receiver at rkm 231. One other American shad was detected by this receiver, but there is insufficient evidence to suggest that it moved upstream beyond that point. Unfortunately, manual tracking above rkm 231 was limited to three events (May 16, May 24, and June 7) due to logistical, time, and access restraints. The uppermost relocation was at rkm 252, based on manual tracking.

Nineteen striped bass were relocated and all fish initially moved downstream of the release site at rkm 219 (Figures 14-17). Two striped bass that initially moved downstream, within range of the receiver at LD-1, made secondary movements upstream using the fish locking procedure (Figure 15). Striped bass 3276 (586 mm, male) successfully locked through LD-2, while striped bass 3275 (589 mm, male) passed back upstream of LD-2 and LD-3, and continued on past the furthest upstream receiver located at rkm 231. Although these fish were not

manually detected below LD-1, we speculate that both fish fell below LD-1 and later locked through LD-1 as they began their secondary upstream movement. This is based on the large gap in time between detections at LD-1 from downstream to upstream movement (Figure 15).

Discussion

The plankton sampling strategy used in 2007 was more effective for collecting American shad eggs than the approach used by Dial Cordy and Associates (DCA) in 2006 (Dial Cordy and Associates 2006). Samples were taken below the locks & dams in both cases but our sampling was done during dusk and evening hours, while those in the DCA study were taken during the day. The increased success rate is consistent with findings in the literature that the timing of spawning for American shad is concentrated around the early evening hours (Massman 1952; Walburg and Nichols 1967; Chittenden 1976; Ross et al. 1993).

American shad spawning observations made during the current study further support this idea. Spawning activity was observed on many occasions during evening samples at each lock and dam, but was most frequent at sites below LD-1 and LD-2. This activity was typically occurring all around the boat during the sample. These observations correlate well with the fact that most eggs collected were found to be in the earliest stage of development.

The distribution of American shad eggs collected and the observed spawning activity suggest that most American shad were below LD1. The number of eggs collected decreased by an estimated 80% for each successive dam, based on an exponential model. This trend suggests that passage of American shad beyond the locks and dams remains substantially limited.

No striped bass eggs were found during this study and only 37 were collected during the 2006 study (Dial Cordy and Associates 2006). Ashley and Rachels (2006) characterized the

population of striped bass in the Cape Fear as severely diminished and our findings appear to reflect that assessment.

American shad and striped bass demonstrated very different reactions to trap and transport activities. Eleven of the 20 tagged American shad from this study moved upstream after release, and of the 9 that initially moved downstream, three of those later moved back upstream. Furthermore, four of the 12 fish that moved upstream went beyond the uppermost stationary receiver (rkm 231). Striped bass, on the other hand, responded very poorly to stress, with all fish making immediate downstream movements upon release and only two fish making secondary movements upstream. However, both striped bass that moved back upstream made use of the locking procedure at more than one lock and dam. This claim is based on the fact that water levels during the periods at which they moved beyond the dams were insufficient to provide passage over the dam. Previous studies have shown that both American shad and striped bass exhibit a strong fallback response (movement downstream after release) to the handling stress of tagging procedures (Carmichael et al. 1998; Beasley and Hightower 2000; Bowman 2001; Hightower and Sparks 2003).

Manual tracking data were limited and stationary receivers provided the majority of the relocation data. This was due in part to the time required for plankton sampling, but also because the focus of the telemetry component of the study was on the movements of fish above LD-3. However, sixteen American shad and three striped bass were manually relocated but no areas of concentration were revealed. Relocations ranged from rkm 97 just below LD1, to rkm 252 below Erwin, NC. Unfortunately, tracking was very limited above the uppermost receiver (rkm 231) due to the extensive shoal areas and lack of river access. Therefore, only three of the five fish that moved beyond that point were relocated.

Data from stationary receivers did, however, reveal interesting short range movement patterns among American shad. For example, shad 2416 (Figure 12) made a series of upstream and downstream movements in and out of range of the receiver above LD3. This same pattern was exhibited, although not quite as strong, by several other American shad in the study. Identifying this pattern earlier on and making extended telemetry observations of the individual fish will likely be an objective for the upcoming field season.

We propose to make some changes in protocol for the 2008 field season. One priority will be to try and minimize the stress placed on striped bass. We recommend eliminating the transport of striped bass upstream for release. Instead, fish would be collected from the lower river (below LD-1) and tagged as early in the year as possible (e.g. January-February) to allow more time for recovery. Given the rate at which fish 3275 and 3276 moved upstream during the 2007 season, we might end up with more fish in the upper river using this revised approach.

Another proposed change would be to modify the stationary receiver array by placing two additional receivers in the portion of the river above rkm 231. This section of the river is difficult to track by boat because of limited access and the many shoals. Having one or more additional receivers would allow us to track fish that move into these less accessible areas more efficiently by narrowing our area of focus. Finally, the Lillington egg sampling station will be relocated to an area of more consistent flow so as to maximize potential for egg capture.

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Table 1. Coordinates, average temperature, dissolved oxygen, depth, volume of water sampled, and number of eggs collected per 1000 m^3 of water sampled for each egg sampling location on the Cape Fear River, NC. Results based on all samples taken at each location between 9 March 2007 and 31 May 2007.

Site (rkm)	Latitude	Longitude	Temperature (°C)	DO (mg/L)	Depth (m)	Sample Volume (m^3)	Eggs/1000 m^3
Lock and dam 1 (97)	34.40162	78.29027	18.7	7.44	7.0	135	264.09
Lock and dam 2 (149)	34.62542	78.56971	18.6	7.37	6.5	105	34.73
Lock and dam 3 (186)	34.83112	78.82211	18.8	8.06	3.6	118	11.67
Fayetteville (226)	35.11154	78.85572	18.9	8.06	4.1	124	1.09
Lillington (273)	35.39417	78.76560	19.1	8.41	1.7	142	0.00

Table 2. American shad eggs and larvae collected from five sites sampled between March 9 and June 1, 2007 on the Cape Fear River, NC. Eggs were categorized by stage of development using criteria provided by Jones et. al. (1978).

Site (Rkm)	Number of Eggs by Stage of Development					Total # Eggs	Total Larvae
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5		
LD 1 (97)	466	6	0	2	1	**475**	**6**
LD 2 (149)	70	8	1	2	1	**82**	**10**
LD 3 (186)	21	8	0	0	0	**29**	**0**
Fayetteville (226)	2	0	0	0	0	**2**	**0**
Lillington (273)	0	0	0	0	0	**0**	**0**
Total	**559**	**22**	**1**	**4**	**2**	**588**	**16**

Table 3. April 4, 2007 tag retention experiment conducted at the NC Wildlife Resources Commission's Watha Hatchery. Ten American shad were implanted with VEMCO V9-1L-R04K coded transmitters and an additional 11 were held as controls. Fish were held in a round hatchery tank and observed over a five-day period for mortality and tag expulsion. There were no mortalities among the control fish.

Fish #	Total length (mm)	Sex	Expelled Tag	Mortality
1	465	M	No	Yes ~3 days after tagging
2	450	M	No	No
3	475	M	No	No
4	425	M	No	No
5	436	M	No	Yes ~12 hrs after tagging
6	415	M	No	No
7	525	F	No	No
8	426	M	No	No
9	455	M	No	No
10	455	M	No	No

Table 4. Date of release, tag identification number, sex, and total length for American shad implanted with VEMCO V9-1L-R04K coded transmitters during the 2007 field season. Release treatments indicate whether or not fish were held in the instream holding pen or released directly into the river. Duration listed (hours) indicates how long fish were held with the door closed. The total number of fish held is given; tagged fish are identified by (T) and untagged by (U). First receiver detection refers to stationary receivers; fish not detected = ND.

Release Date	Tag ID	Sex	TL (mm)	Release Treatment	First Receiver Detection
4/24/07	2415	M	423	24 hrs, Am. shad: 5(T) 10(U), striped bass: 2(T)	95 Bridge
4/24/07	2418	M	427	24 hrs, Am. shad: 5(T) 10(U), striped bass: 2(T)	301 Bridge
4/24/07	2422	M	451	24 hrs, Am. shad: 5(T) 10(U), striped bass: 2(T)	95 Bridge
4/24/07	2424	M	471	24 hrs, Am. shad: 5(T) 10(U), striped bass: 2(T)	95 Bridge
4/24/07	2426	M	418	24 hrs, Am. shad: 5(T) 10(U), striped bass: 2(T)	95 Bridge
5/3/07	2430	M	482	4 hrs, Am. shad: 5(T) 6(U)	301 Bridge
5/3/07	2431	F	509	4 hrs, Am. shad: 5(T) 6(U)	301 Bridge
5/3/07	2432	M	432	4 hrs, Am. shad: 5(T) 6(U)	95 Bridge
5/3/07	2433	F	513	4 hrs, Am. shad: 5(T) 6(U)	95 Bridge
5/3/07	2434	F	482	4 hrs, Am. shad: 5(T) 6(U)	301 Bridge
5/9/07	2416	F	473	Door left open, Am. shad: 7(T), leave at will	95 Bridge
5/9/07	2417	F	477	Door left open, Am. shad: 7(T), leave at will	301 Bridge
5/9/07	2419	F	540	Door left open, Am. shad: 7(T), leave at will	95 Bridge
5/9/07	2420	F	529	Door left open, Am. shad: 7(T), leave at will	95 Bridge
5/9/07	2421	F	512	Door left open, Am. shad: 7(T), leave at will	ND
5/9/07	2423	F	518	Door left open, Am. shad: 7(T), leave at will	ND
5/9/07	2425	F	487	Door left open, Am. shad: 7(T), leave at will	301 Bridge
5/14/07	2427	M	415	Directly into river, no pen.	301 Bridge
5/14/07	2428	F	500	Directly into river, no pen.	301 Bridge
5/14/07	2429	F	500	Directly into river, no pen.	301 Bridge

Table 5. Date of release, tag identification number, sex, total length, and total time spent in surgery for striped bass implanted with VEMCO V9-1L-R04K coded transmitters during the 2007 field season. Release treatments indicate whether or not fish were held in the instream holding pen or released directly into the river. Duration listed (hours) indicates how long fish were held with the door closed. The total number of fish held is given; tagged fish are identified by (T) and untagged by (U). First receiver detection refers to stationary receivers; fish not detected = ND.

Release Date	Tag ID	Sex	TL (mm)	Surgery Time (min)	Release Treatment	First Receiver Detection
4/13/07	3269	M	515	15	Directly into river, no pen.	95 Bridge
4/13/07	3270	M	796	17	Directly into river, no pen.	95 Bridge
4/13/07	3271	F	792	15	Directly into river, no pen.	95 Bridge
4/13/07	3272	F	754	10	Directly into river, no pen.	95 Bridge
4/13/07	3273	M	559	11	Directly into river, no pen.	95 Bridge
4/13/07	3274	M	761	11	Directly into river, no pen.	95 Bridge
4/24/07	3275	M	589	13	24 hrs, striped bass:2(T), Am. shad:5(T) 10(U)	95 Bridge
4/24/07	3276	M	586	12	24 hrs, striped bass:2(T), Am. shad:5(T) 10(U)	95 Bridge
5/7/07	3277	M	803	8	Directly into river, no pen.	95 Bridge
5/7/07	3278	F	838	8	Directly into river, no pen.	95 Bridge
5/7/07	3279	M	577	10	Directly into river, no pen.	95 Bridge
5/7/07	3280	M	665	7	Directly into river, no pen.	95 Bridge
5/7/07	3281	M	571	7	Directly into river, no pen.	95 Bridge
5/7/07	3282	F	613	13	Directly into river, no pen.	95 Bridge
5/7/07	3283	M	710	8	Directly into river, no pen.	95 Bridge
5/7/07	3284	M	567	11	Directly into river, no pen.	95 Bridge
5/7/07	3285	M	636	6	Directly into river, no pen.	95 Bridge
5/7/07	3286	M	585	7	Directly into river, no pen.	ND
5/7/07	3287	M	560	6	Directly into river, no pen.	95 Bridge
5/7/07	3288	M	538	7	Directly into river, no pen.	95 Bridge

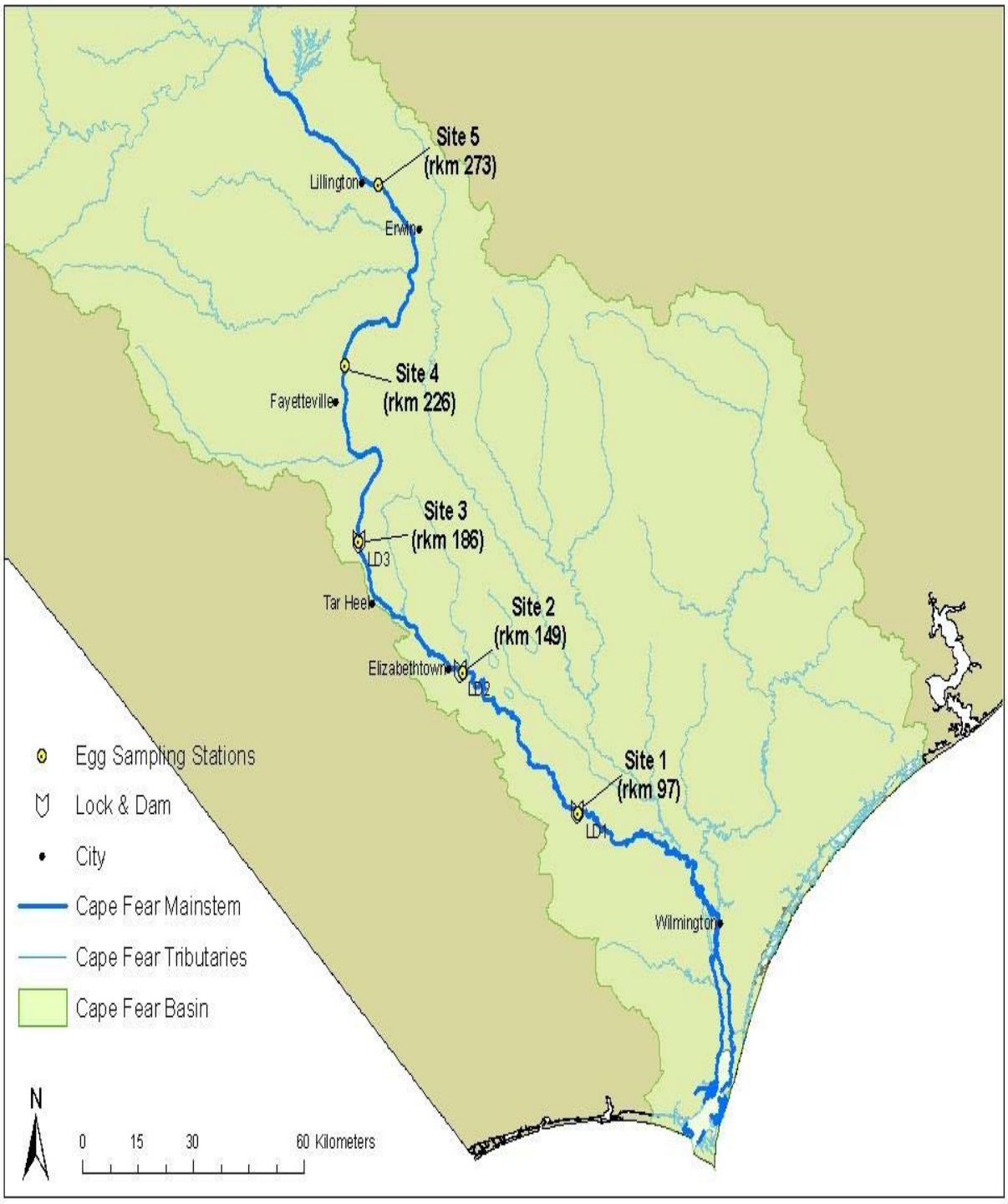

Figure 1. Location and associated river km of egg sampling stations within the Cape Fear river during the 2007 field season. Locks and dams, as well as cities are shown for reference.

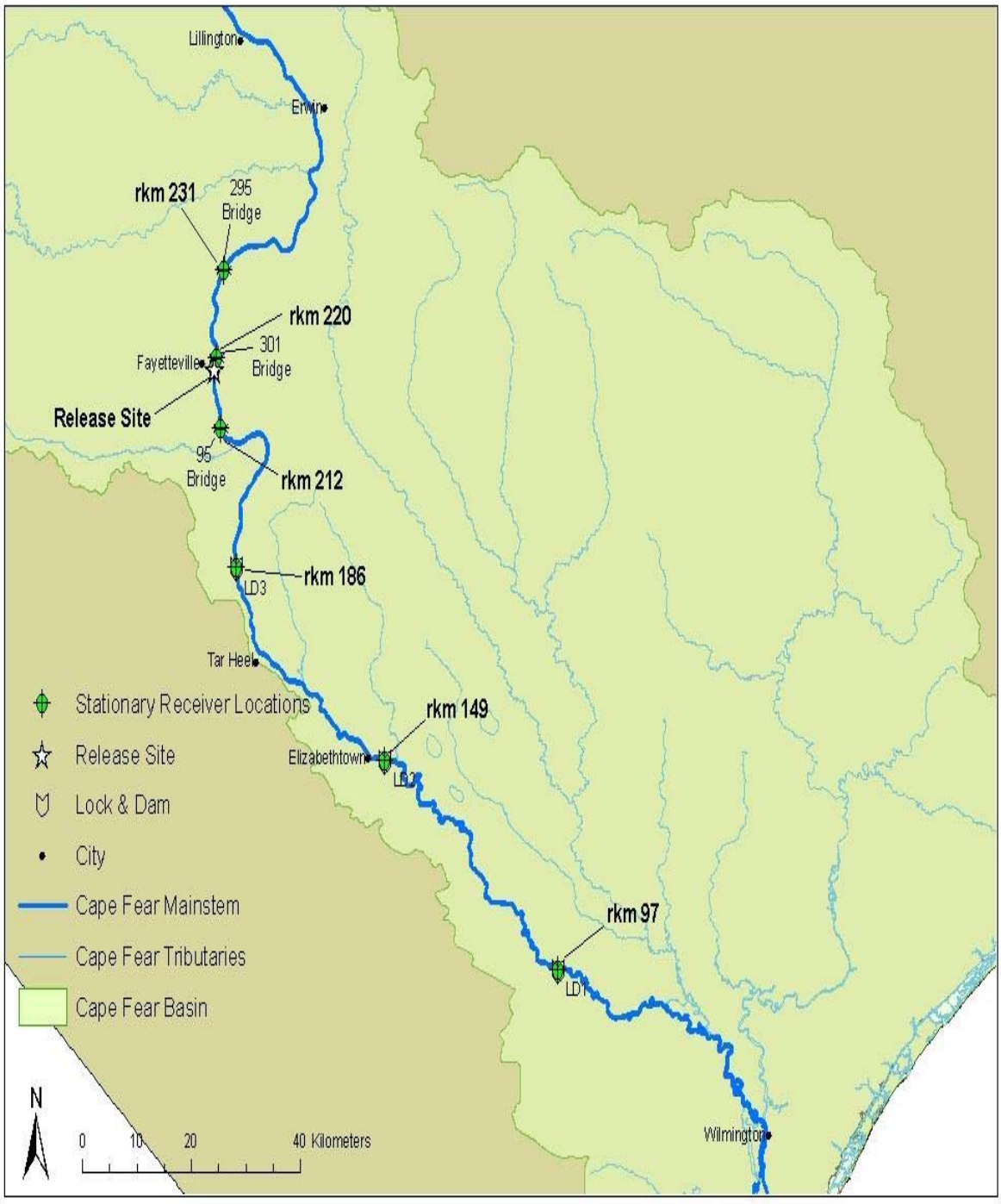

Figure 2. Location and associated river km of stationary receivers and fish release site within the Cape Fear River during the 2007 field season. Locks and dams, as well as cities are shown for reference.

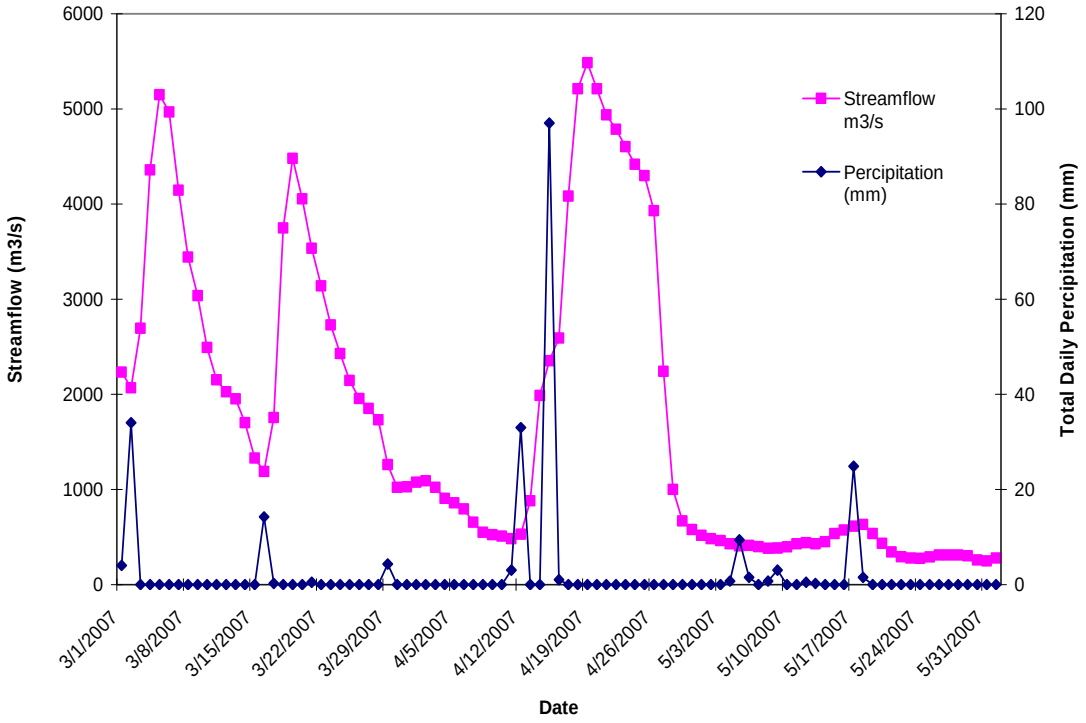

Figure 3. Average daily streamflow (m^3/s) and total daily precipitation (mm) data from March 1 to June 1, 2007 from the USGS gauge at lock and dam 1 on the Cape Fear River, NC.

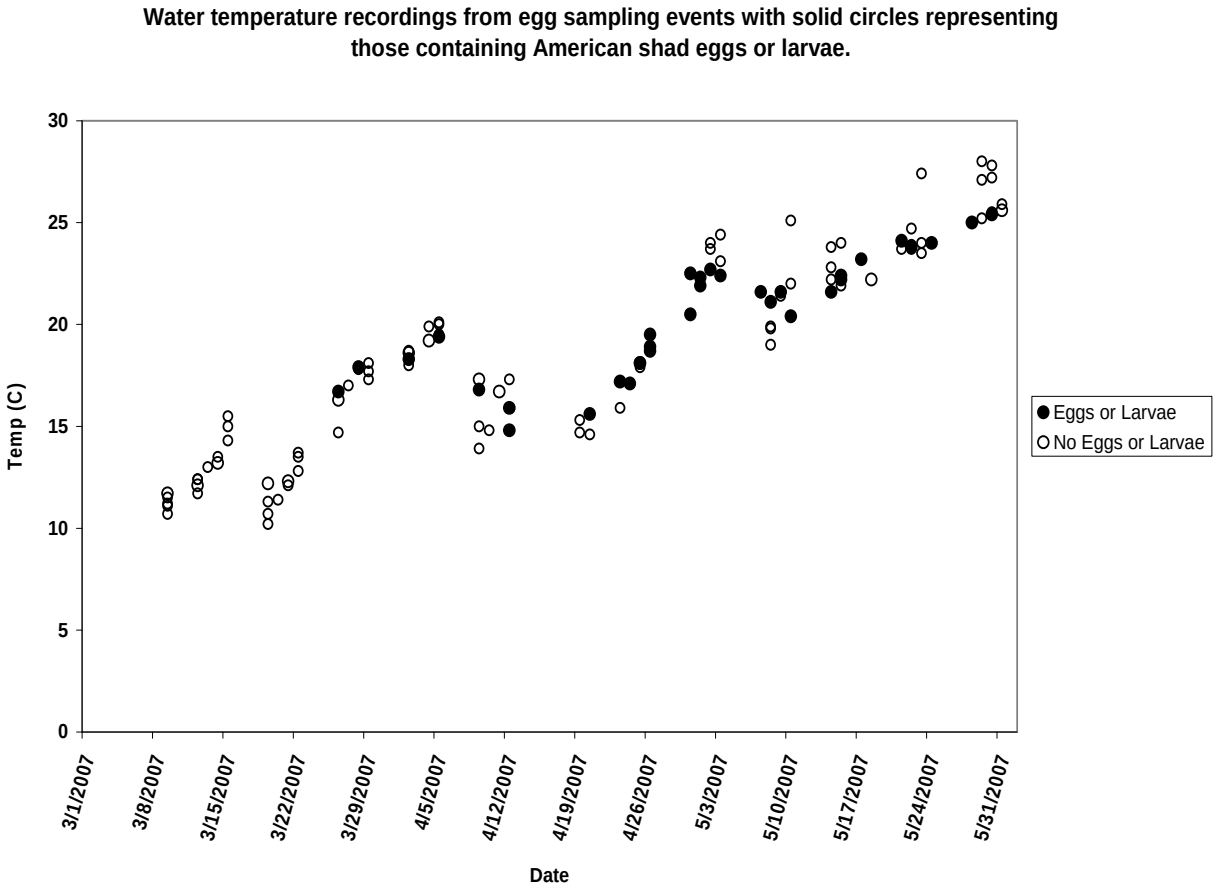

Figure 4. Water temperature and American shad egg or larvae presence/absence over all sites on the Cape Fear River during the 2007 field season.

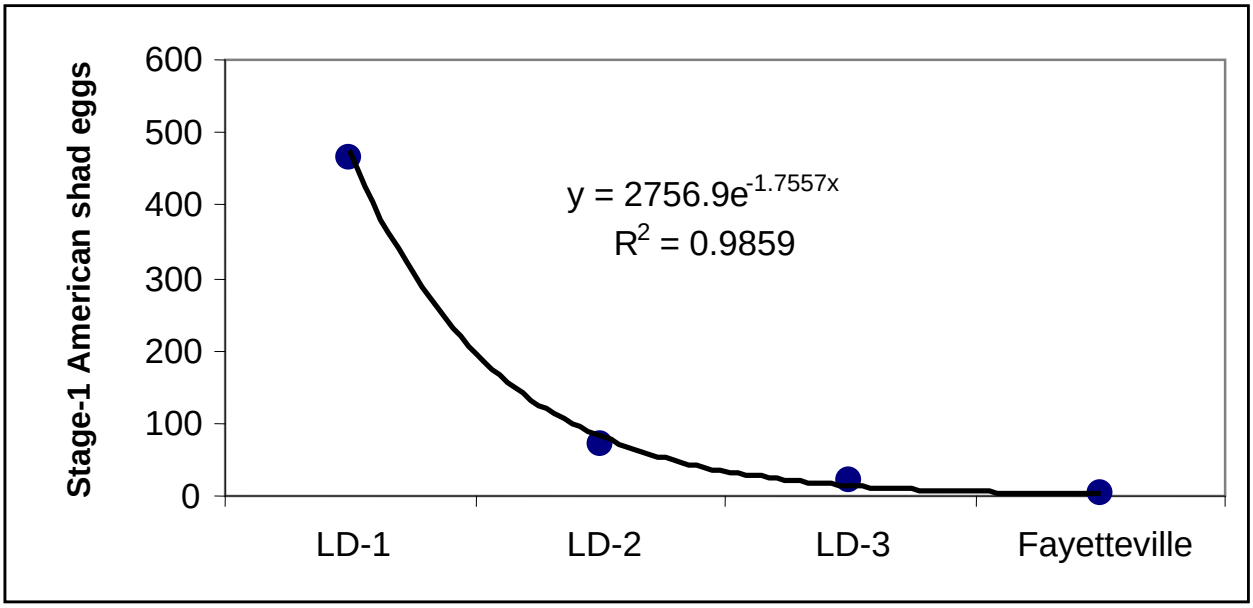

Figure 5. Number of stage-1 American shad eggs collected at sites 1-4 on the Cape Fear River, March 9-June 1, 2007. The line is an exponential model fitted using least squares.

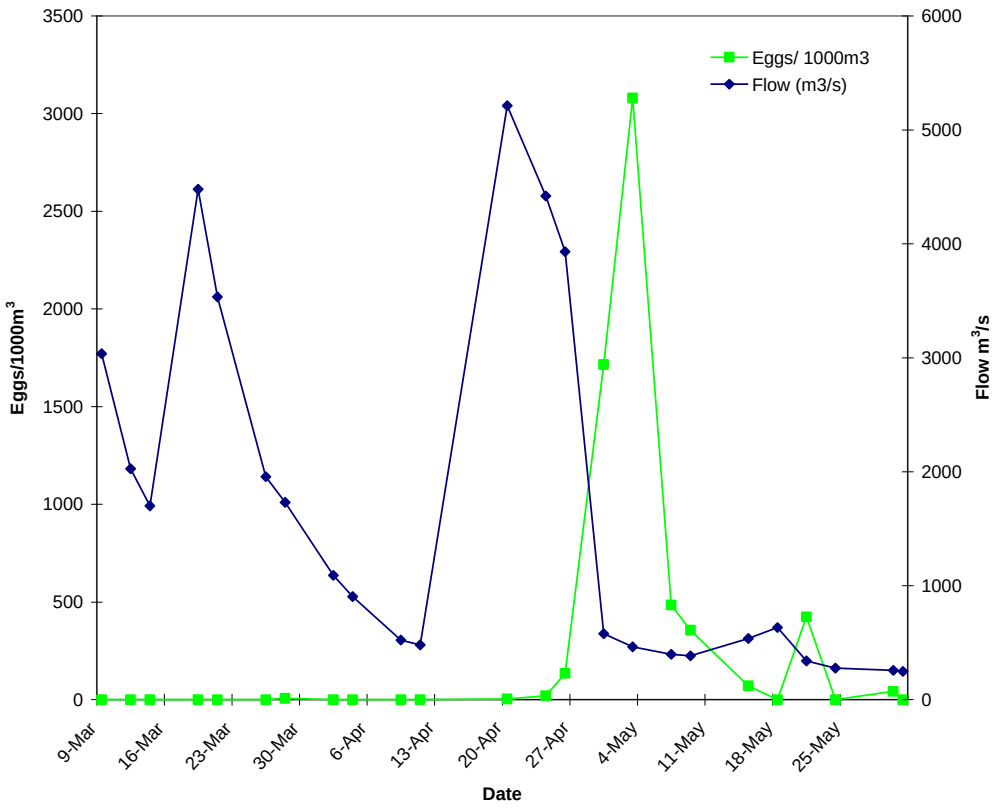

Figure 6. Density (eggs/1000 m^3) of American shad eggs and streamflow (m^3/s) for samples at site#1 (rkm 97) below lock and dam 1 on the Cape Fear River during the 2007 field season.

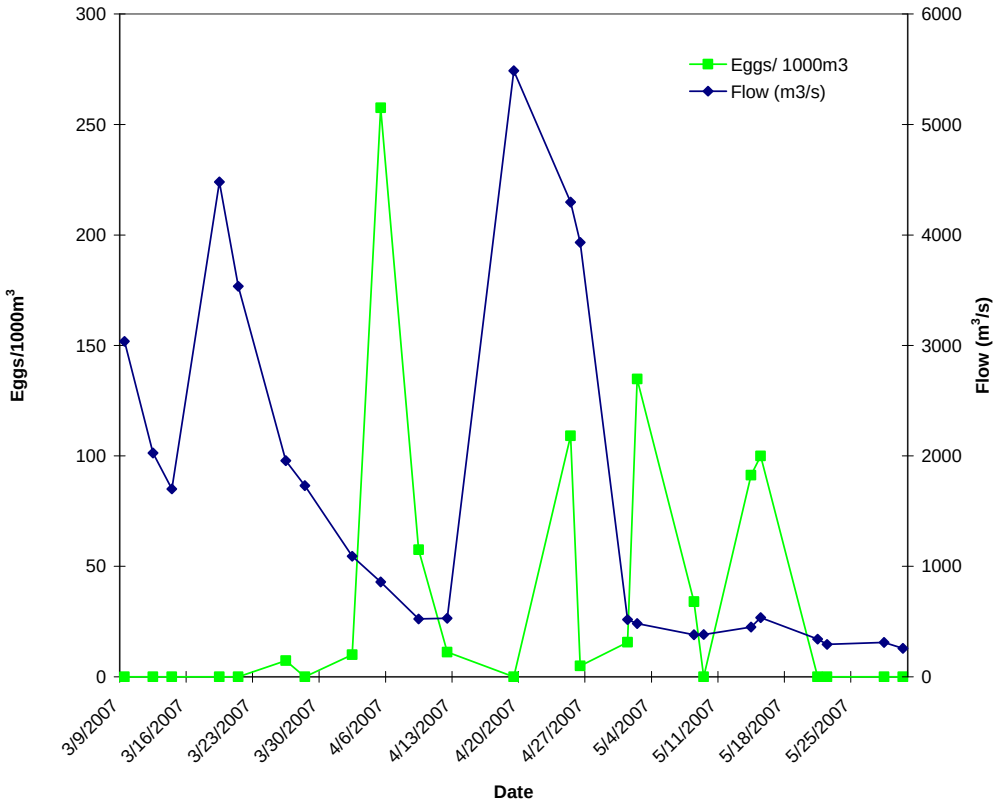

Figure 7. Density (eggs/1000m^3) of American shad eggs and streamlow (m^3/s) for samples at site#2 (rkm 149) below lock and dam 2 on the Cape Fear River during the 2007 field season.

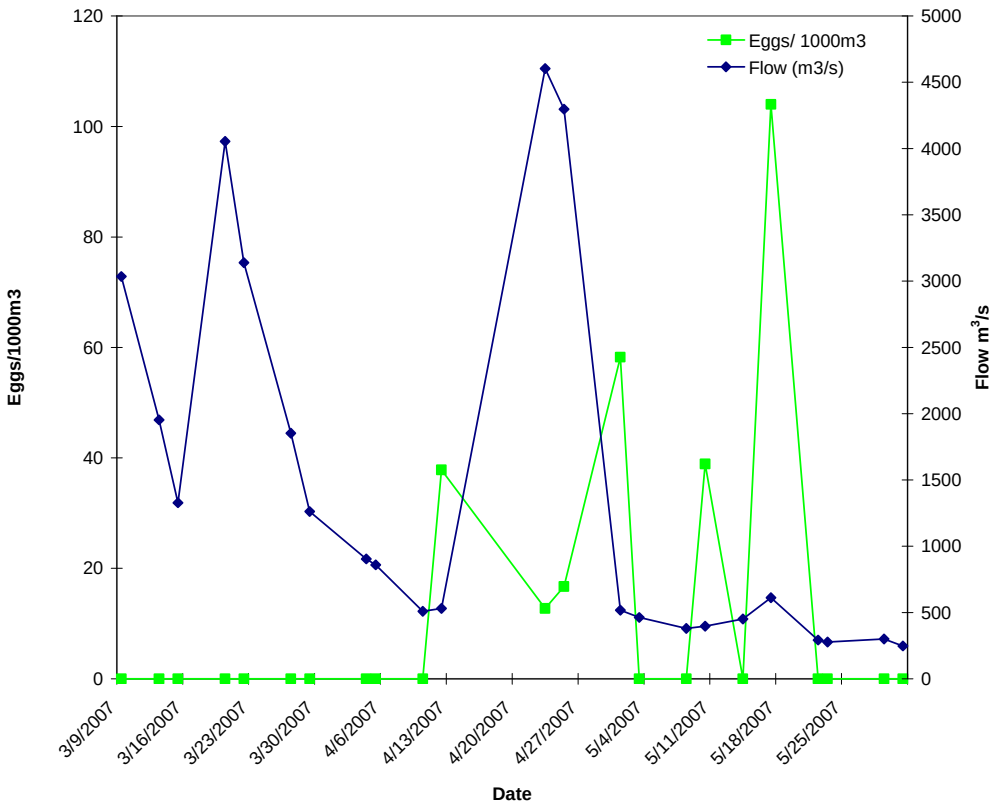

Figure 8. Density (eggs/1000m^3) of American shad eggs and streamlow (m^3/s) for samples at site#3 (rkm 186) below lock and dam 3 on the Cape Fear River during the 2007 field season.

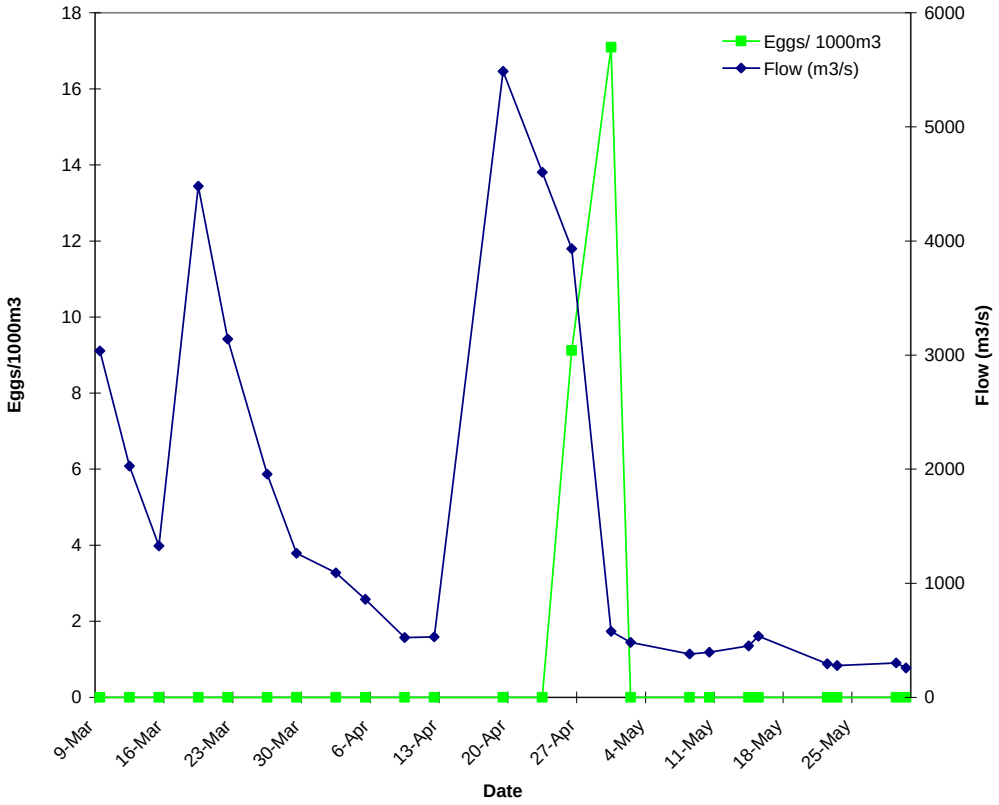

Figure 9. Density (eggs/1000m^3) of American shad eggs and streamlow (m^3/s) for samples at site#4 (rkm 226) near Fayetteville, NC on the Cape Fear River during the 2007 field season.

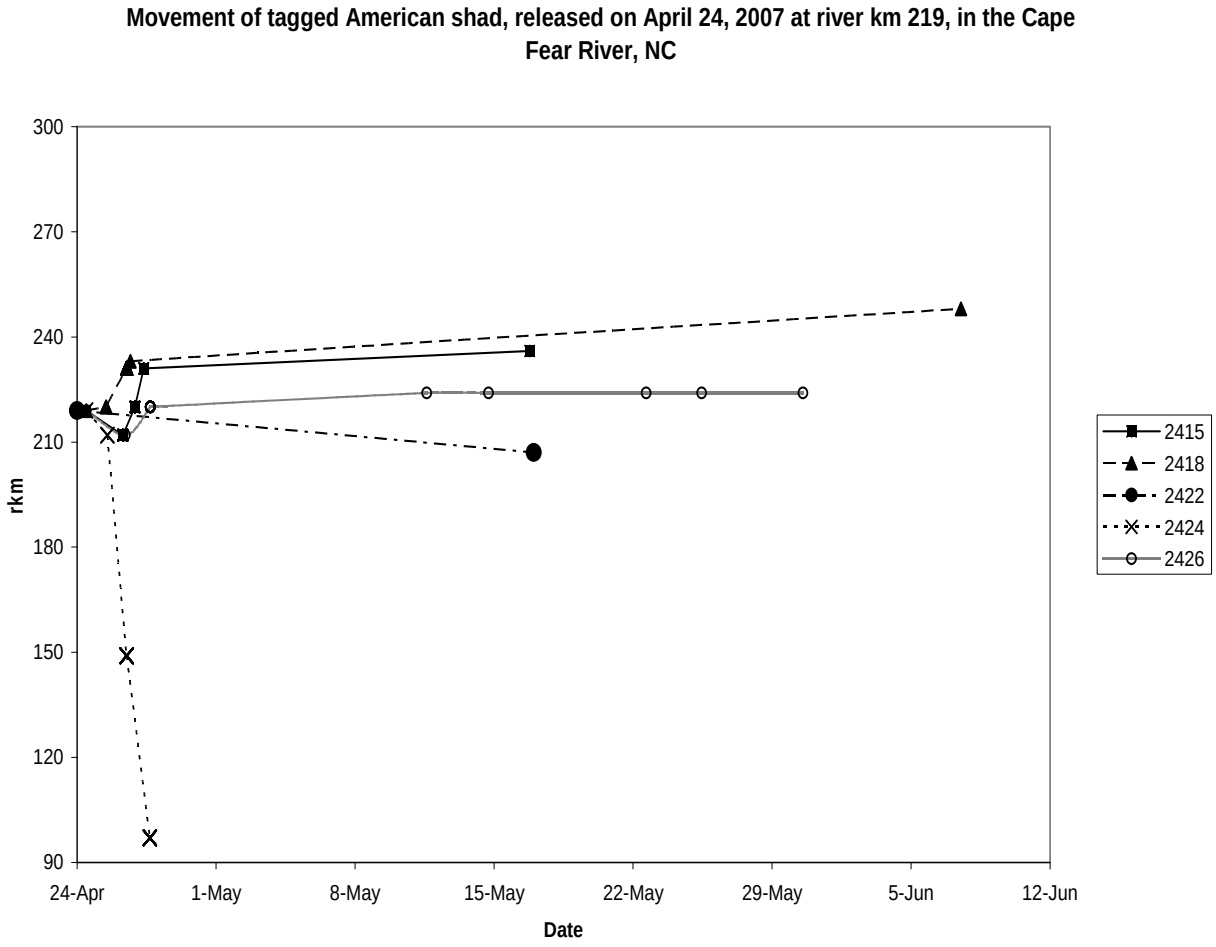

Figure 10. Movement of tagged American shad, released on April 24, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.

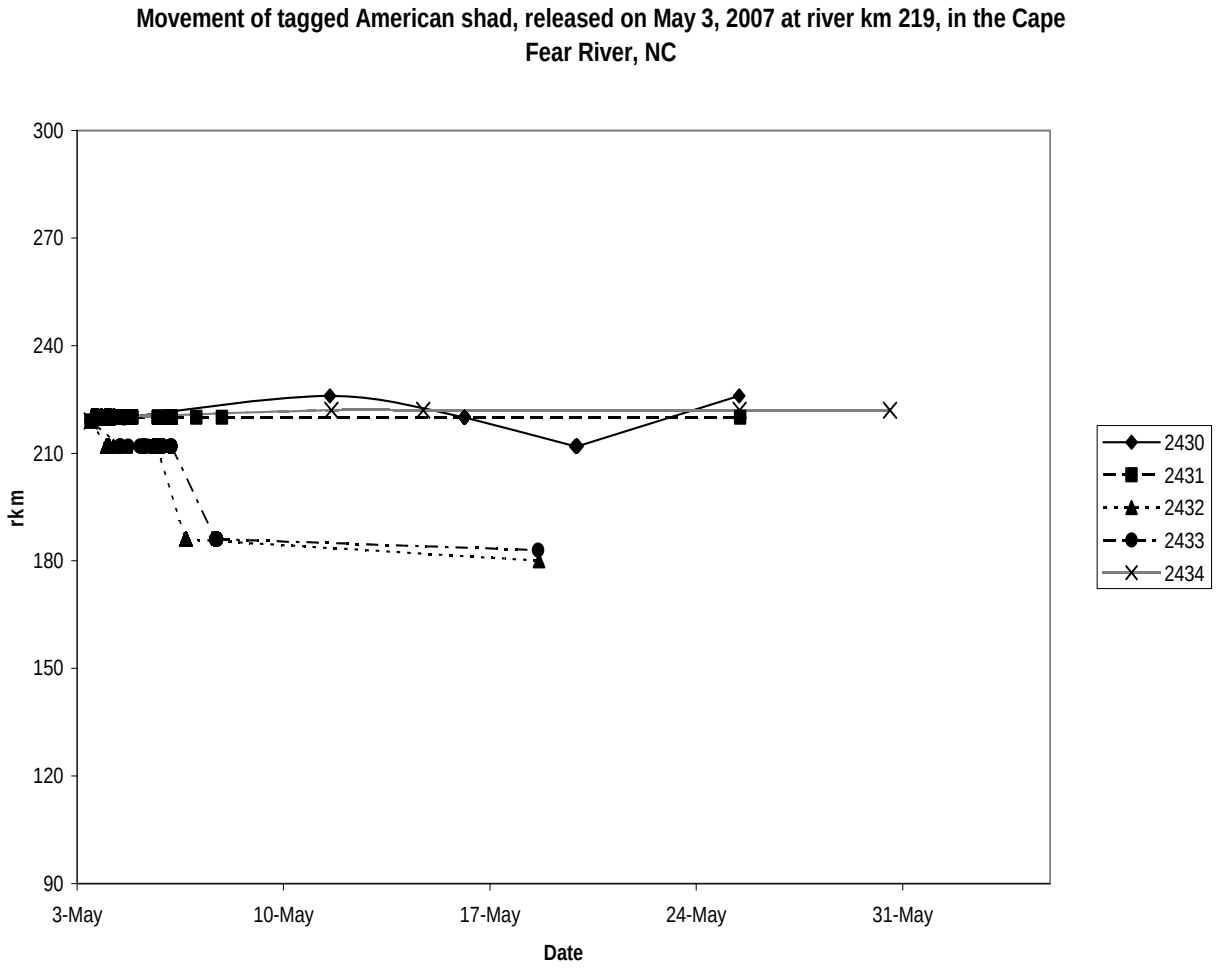

Figure 11. Movement of tagged American shad, released on May 3, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.

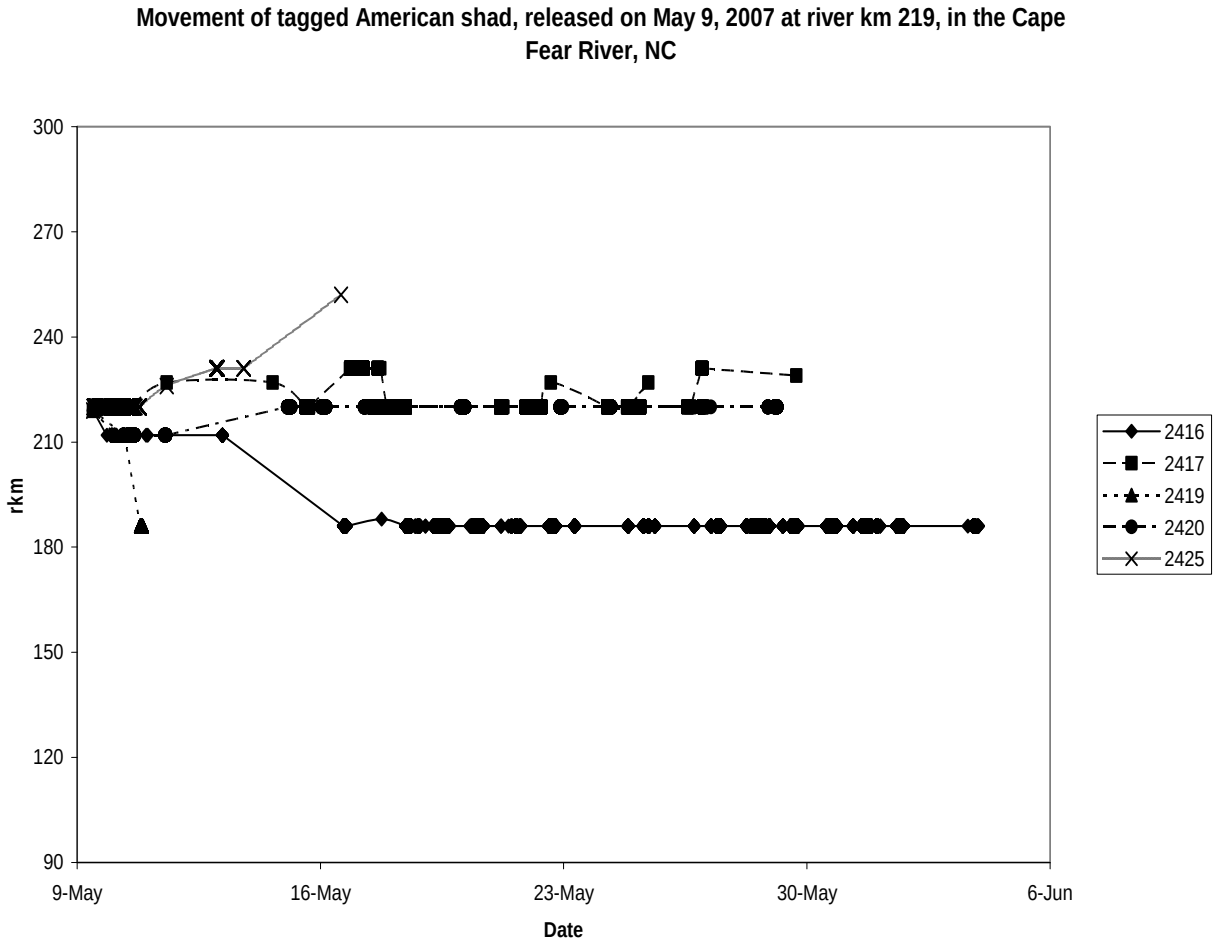

Figure 12. Movement of tagged American shad, released on May 9, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.

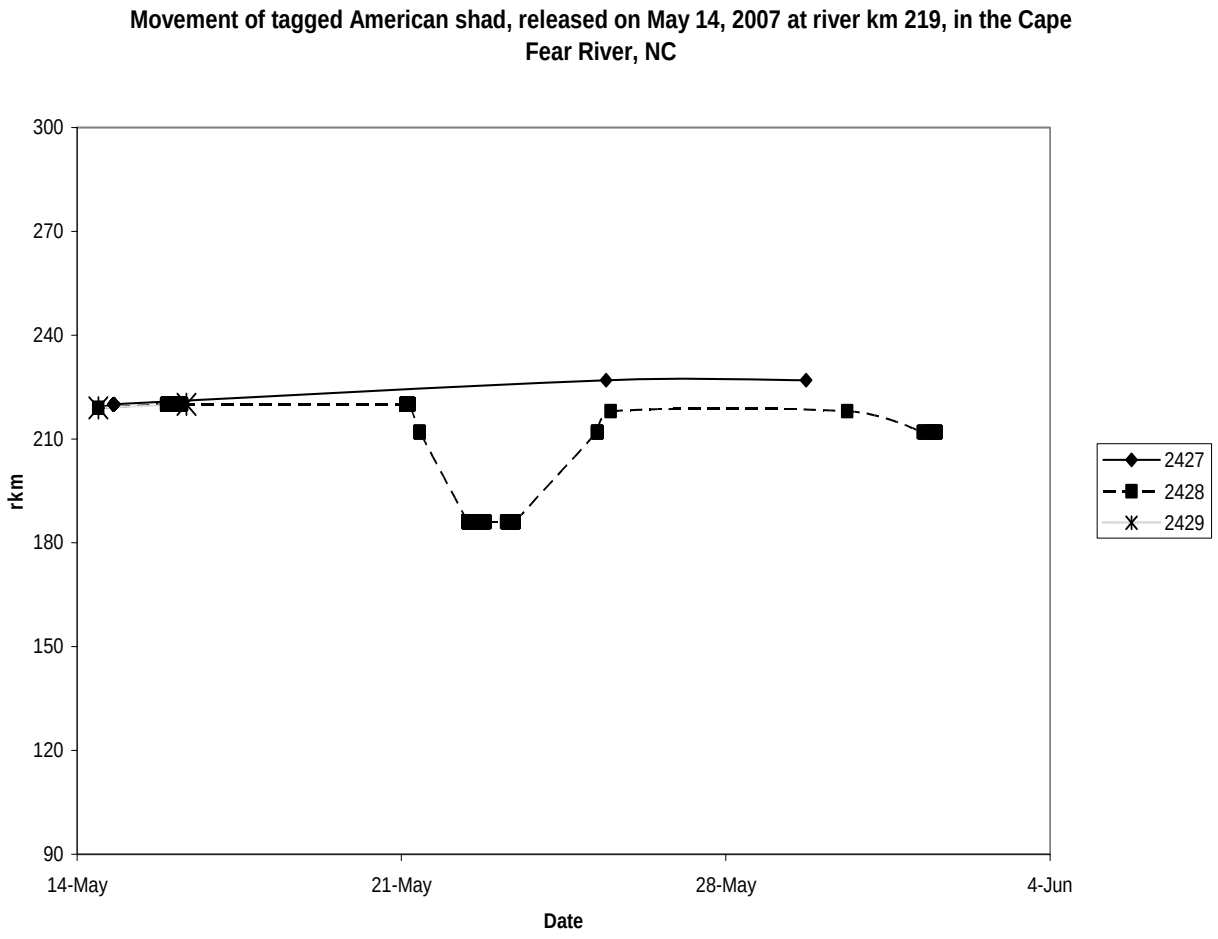

Figure 13. Movement of tagged American shad, released on May 14, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking . Legend numbers correspond to tag numbers of individual fish.

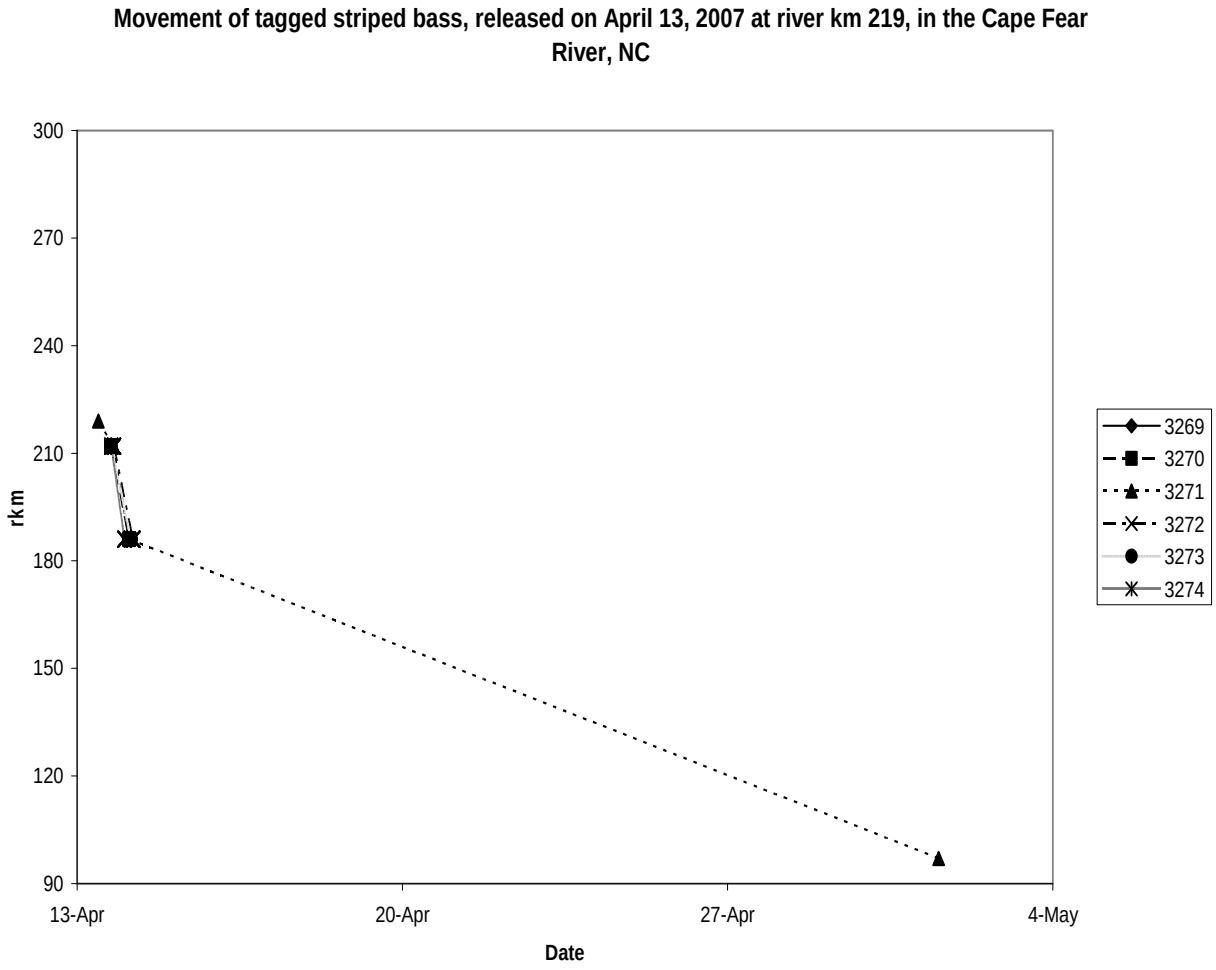

Figure 14. Movement of tagged striped bass, released on April 13, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking . Legend numbers correspond to tag numbers of individual fish.

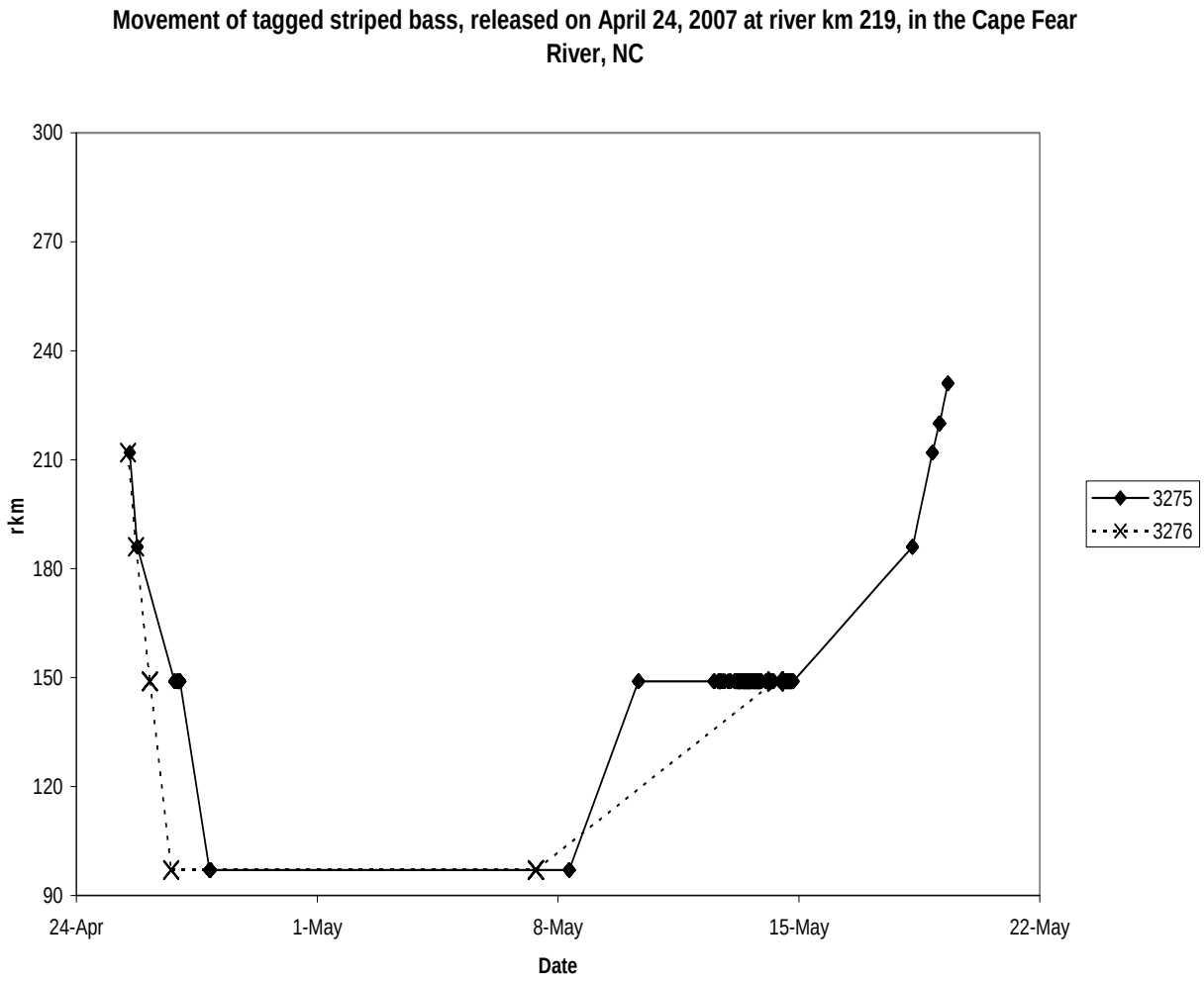

Figure 15. Movement of tagged striped bass, released on April 24, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.

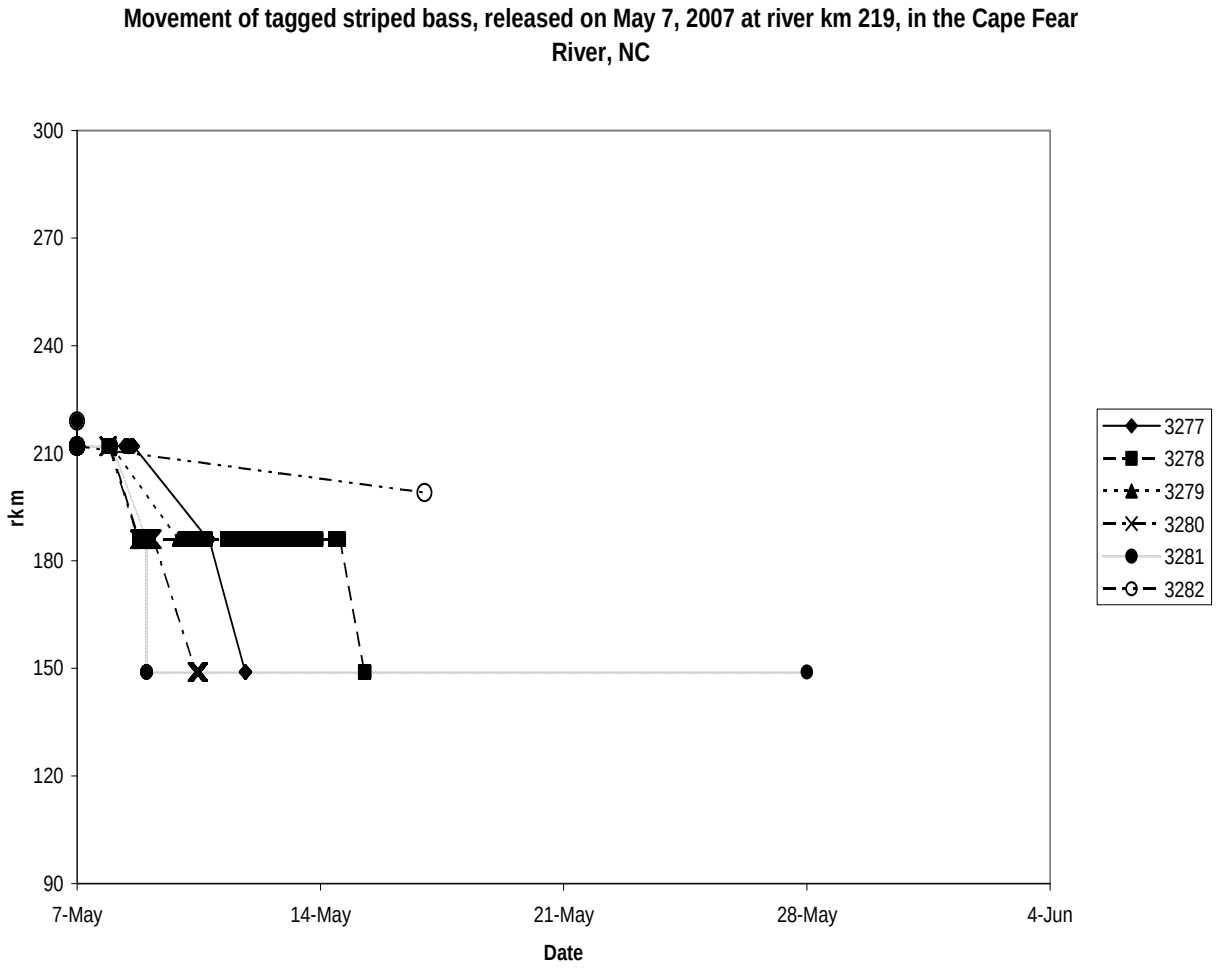

Figure 16. Movement of tagged striped bass, released on May 7, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.

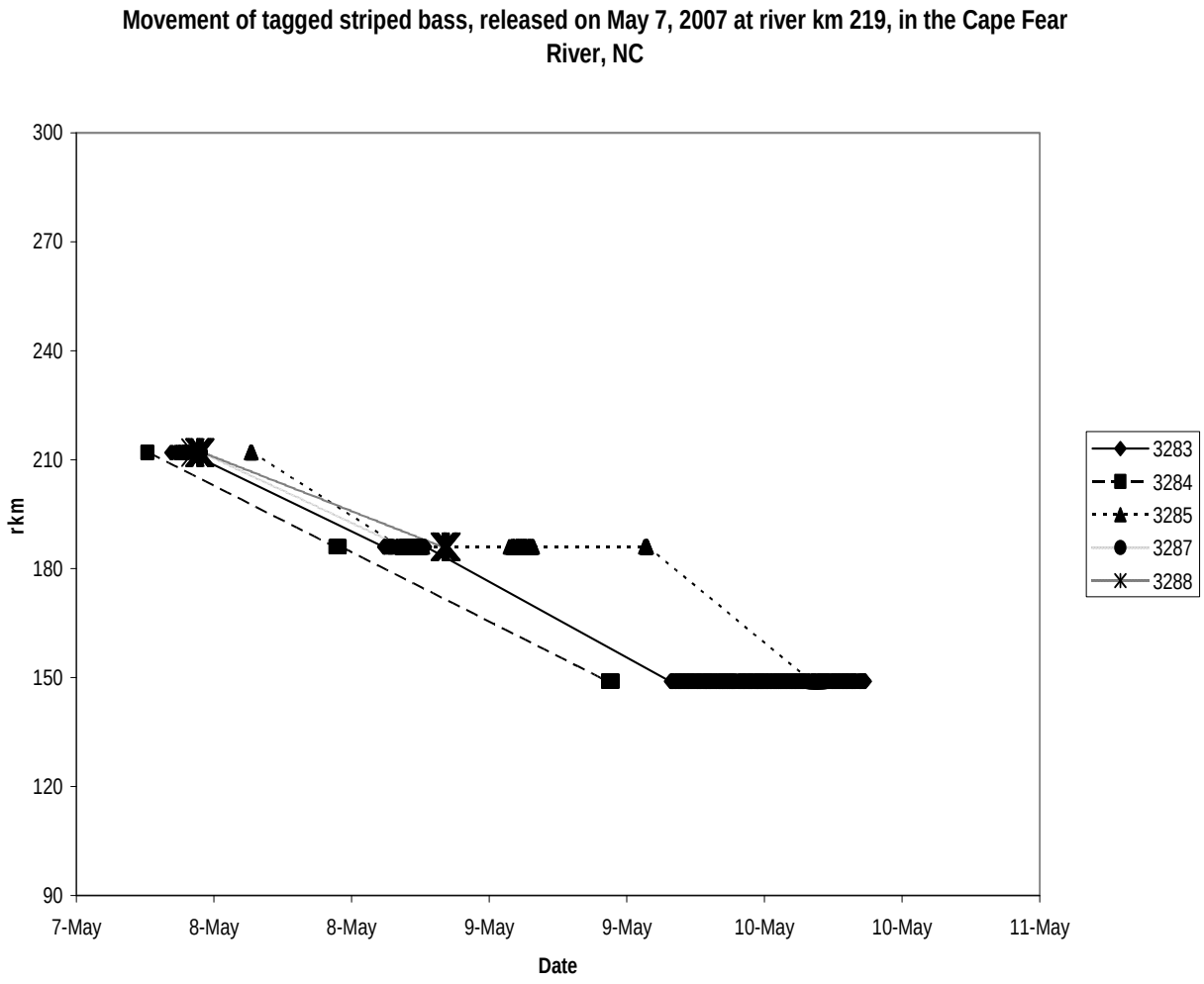

Figure 17. Movement of tagged striped bass, released on May 7, 2007 at river km 219 in the Cape Fear River, NC. Locations are based on results of both stationary receivers and manual tracking. Legend numbers correspond to tag numbers of individual fish.